Defects in Materials
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Lecture – 27
Dislocations in BCC and HCP

The last few classes, we discussed in detail the different types of dislocations which can form in FCC lattice and the various ways in which different type of dislocations can repeat into partials all this things we have looked at it. Other important crystals structures in which most of the metals especially important metals like ion, titanium, zirconium and all this materials or transition metals like molibnium, niobium, chromium, all these crystallizing to is BCC or HCP structure. What will do today is to look briefly at dislocations in BCC and HCP type of metals when we look at the crystal structure of BCC what all the vectors the we can get is it the small translation vectors perfect translation vectors.

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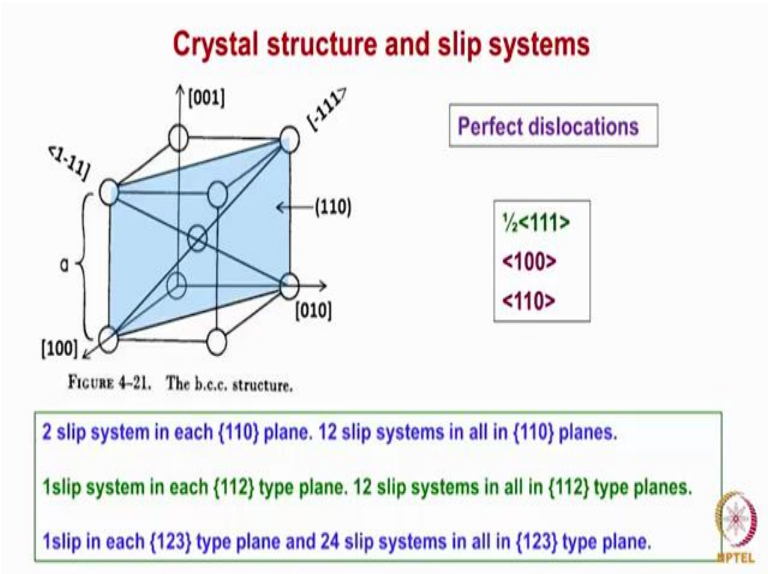

They are if you look in increasing order of magnitude half 111 type, 100 type then comes 110 type, if you look at this translation vectors the one which will qualify or which can qualify to be the burgers vector for the dislocation in BCC lattice is half 111. If you look at the crystal structure that is the shortest not only the translation vector that is the close packed direction also.

Because. In fact, in BCCs there is only one close packed direction which is along 111 direction, these 111 direction can lie along essentially 6 110 planes that is if you consider number of slips that is in each 110 plane if you consider there are 2 close packed directions are there. So, 6 planes are there, totally we will have 12 slips systems. Similarly if you consider 112 plane that is because in BCC structure 110, 112 as well as 123 all of them have got almost the same packing density. So, the dislocations can move on all these planes whereas, the case of FCC which we considered there 111 is the close packed structure, here none of the structures are close packed, but they have got almost the similar packing density they are the best which packing density which is available in terms of the various types of planes which we can consider in BCC lattice.

Because of that 112 plane also could be a potential slip plane, there only one 111 direction is there, but there are 12 111 planes are there. So, 12 slips systems are possible then if you look at 123 plane also, there is only one 111 direction is there, but 123 planes if you consider, there are 24 planes are there distinct planes. So, if we look at the total number of slip planes which are available for a particular dislocation perfect dislocations in BCC there are total 48. Let us look at the case of any particular 111 direction that direction any particular specific 111 direction, if we take it that can be contained by 3 110 type of plane then 3 112 type of planes and 6 123 type of slip planes all of them the common intersection could be a specific 111 direction.

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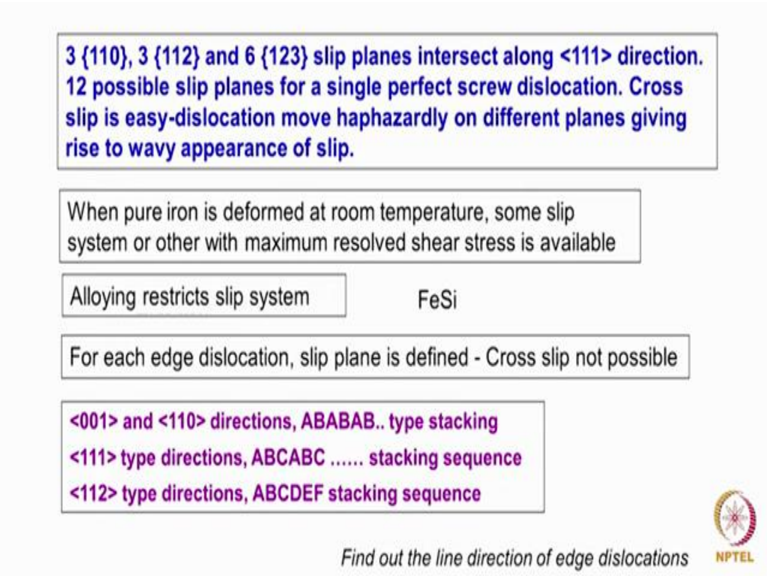

So, if the dislocation is a screw dislocation, the dislocation can easily cross slip from one plane to the other without any problem. So, cross slip becomes very easy. So, it will be merely moving from one plane to the another depending upon the way in which the maximum critical resolve shear stress is there because of this the slip gives a wavy appearance where as in the case of FCC, it is specified the this is the planes, in plane in which that is location moves here there are so many possibilities are there and the since all of them have got one or the other because since all them are inclined with respect to each other one plane or the other they will have the maximum resolve shear stress. So, that it can easily move if you take your ion at room temperature since we consider that for each direction there are essentially about 12 planes are possible around that this direction around 12 planes will be there. So, some plane or the other will have a maximum critical resolve shear stress as I mentioned. So, that it can slip can easily propagate.

But there are many systems all even in ion itself if we do alloying because of some expansions and it has been seen that sometime the slips systems are restricted for example, if you take ion silicon alloys essentially the slip occurs in this or the slip is restricted to 110 type of planes whereas, if you look at h dislocation h dislocation the line direction the burgers vector is not the same not in the same direction burgers vector on the line direction because of that we can define a slip plane and the plane is unique for each slip system.

So, cross slip will not take place if you look at the various directions each of the direction we can look at how atomic layers are packed if you look along 001 direction it is an ABAB type of a stacking where as if you like along 112 type of direction it is 6 layers stacking sequence ABCABCABA not ABCABCDEFABCDEF like that it goes along 111 plane the packing is ABCABC along 110 plane which is the close packed plane the packing is ABAB type of a packing.

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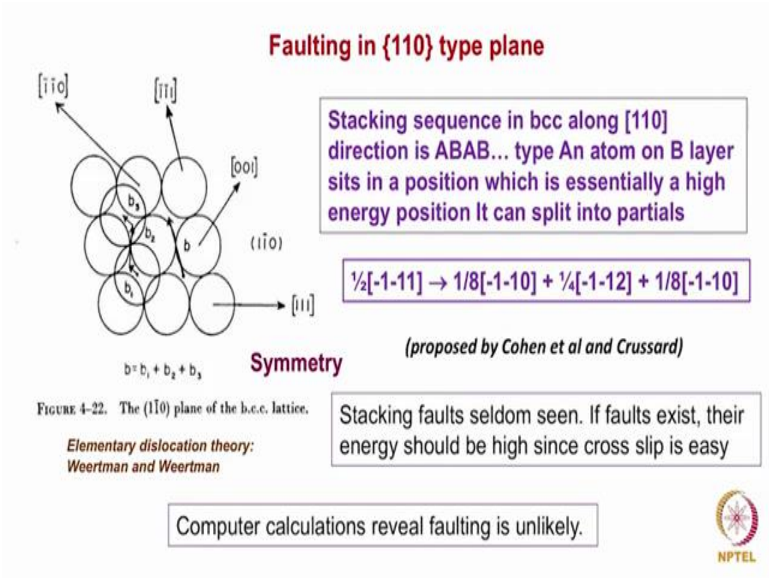

Let us just look at the structure of this location in 110 plane if you look at it, this is a packing along 001 plane, if it is an A layer the B layer will be coming on top of a it. So, this is the position from which it is at the low symmetric position which is quite stable, it just does not move because we have looking at the hardware model, if you look at 110 plane here also the packing is an no; here also the stacking is essentially a ABAB type of a stacking, but if you look at the atom which is sitting on here, it is sitting at A position where either it will move to this direction or to the this direction because they are low energy positions, but from symmetry consideration atom has to be sit at this position.

So, on this basis people called that fault would form here essentially what we are trying to do is we are just looking at how atom which is sitting on the top of it. It should be moved an identical position by a movement of A by 2 112, A by 2 111 this location. So, atom sitting on the top it just comes to A position which is a slightly in low energy position from there it shifts to another low energy position from there it shifts to higher energy position that is how it can reach there.

So, this itself can be represented burgers vector of the perfect dislocation splits into 3 dislocations one with 1 by A 1 bar 1 bar 0, another with 1 by 4 1 bar 1 bar 2 then plus 1 by 8 1 bar 1 bar 0 that is this sort of reaction has been proposed by Cohen and Crusades, but when we people looked at it; that means, if you look at the burgers vector of these dislocations these dislocations are not the translation vectors in BCC lattice.

Because of this because of it this the movement of this dislocation should create a stacking fault correct, but experimental evidence did not show any stacking faults in most of the BCC material they were seldom seen. So, then they thought that the fault energy may be very high because of this only cross slip takes place they do not split into partials because if the dislocations split into partial as we have seen in the case of FCC material if they have to cross slip they have to join together the partial should join together form a perfect dislocation.

Then only they can cross link and in most of the BCC material cross slip also been found easily this is what essentially was the sort of argument which has been put forward or a reasoning which has been put forward later in recent times people have done a lot of computer stimulation work and detail computer calculations have been done taking elastic anisotropy all these factors into consideration and they had also observed that faulting is highly unlikely in BCC material.

So, for we considered about the fault thing now let us look at the course structure of the dislocation itself lot of stimulation work has been done to look at how the core of perfect dislocation looks like in BCC.

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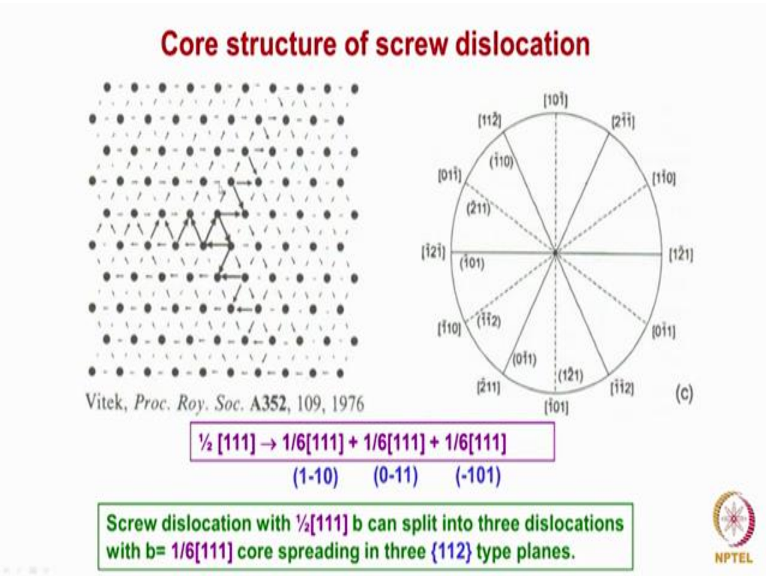

This is from the work of Vitek essentially the dislocation line or the burgers vector comes out of the screen perpendicular to a screen whatever the atom positions which are being shown on the screen are 110 type plane a burgers vector is perpendicular theory and we know that around the dislocation line direction now we are looking for how the displacements of the atom are taking place they are being shown by arrows.

So, after this computer calculations, they had just marked the position of atoms on 110 planes and when the dislocation core is there this center, how the displacements are taking place is it has radial symmetry are not when we look at the figure it is obvious that it does not have a radial symmetry and in these directions the displacements are very high and in these as well as in these direction and these correspondence to the plane on which this directions are lying or 110 type of a plane.

So, essentially the displacement around the screw dislocation that is around the core of the dislocation has split on 3 110 type of planes which contains the dislocation this figure, what we are showing it is a stereogram and the stereogram shows a various directions this is 111 112 type of a direction and this is the plane in this plane, it will contain. So, if you look at it these directions we can identify using this stereogram. So, this is the type that is half 111 dislocation can split into 3 1 by 6 111 type of burgers vector. It can have each of them will be along 3 different 110 type of a plane they can by; that means, the since the core is lying on different planes if the dislocation has to move it is not very easy because they are on 3 directions it has burgers vector component of the burgers vector in 3 planes, correct.

Similarly, if you look very carefully we can notice that even in these directions also we can see some asymmetry of the displacements could be seen even on 112 planes also where some part of the component of the may split into there is especially 1 by 6 111 part of it is in 110 type of a plane part of it is in 112 type of a plane what is essentially interesting is that if you try to deform this material.

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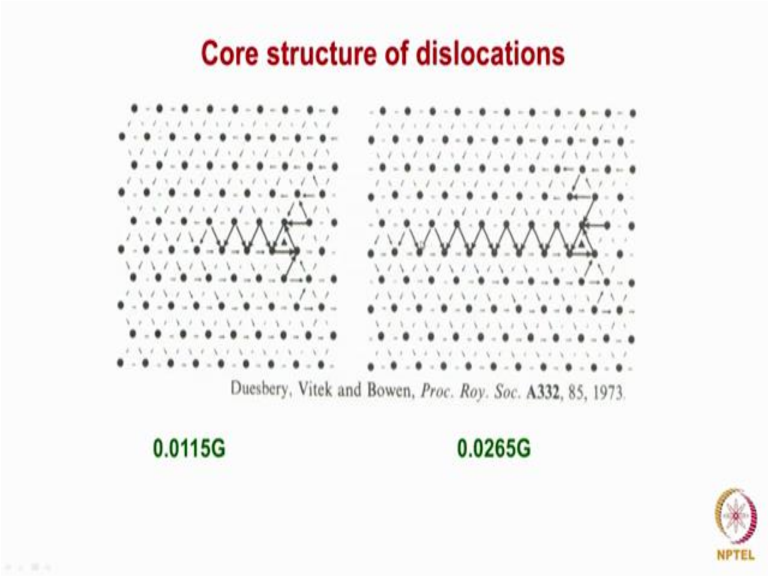

Then what happens is that at difference stresses, here is a very small stress that is essentially it something like 100 of a crores to the shear modulus. It is a quite high stress when the stress is being applied; the displacements now you can see that an asymmetry has come only in this direction the displacement is maximum and the displacement in these directions have reduced the same thing you can see it when the magnitude of the shear stresses has been increase you can see that now it is lying in only one particular 110 type of a plane, correct.

The component of the vectors in that component of the burgers vectors which there in other 2 110 type of planes that has becomes 0. Now it will start moving. So, this is what one peculiarity of dislocation movement especially screw dislocation in BCC lattice and it is a little more complicated then what it appears like in the case of an FCC material because of which there is a difficulty for screw to move and most of the material it has been observed that very long screw dislocations could be had been noticed in BCC type of materials and whereas, hardly any h type of a dislocations are seen let us look at that case of a non screw dislocations how the core of a location.

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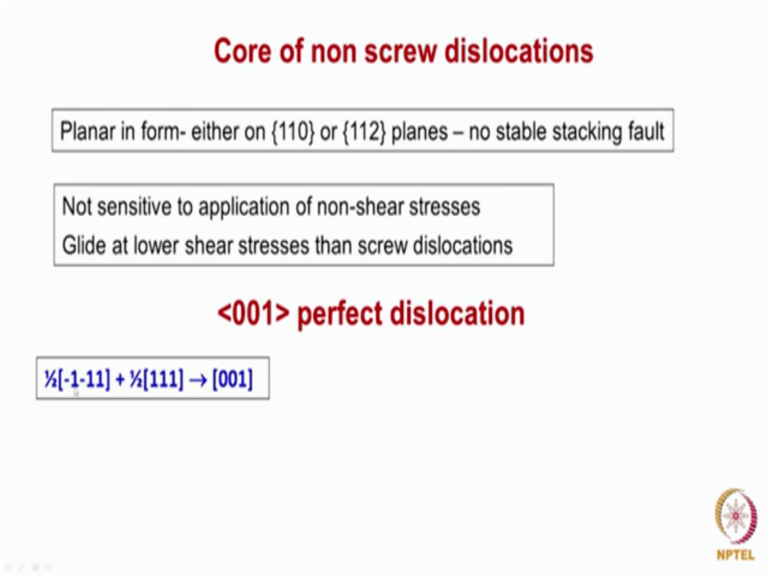

This is what is the observation which has been obtained that either the core lies on either on 110 plane that entire displace most of the displacement lies on that plane. So, that it is easy for them to move, but at the same time no stacking fault has been observed and another observation which is there is that in the case of FCC material when we apply a shear stress for a next dislocation it is very sensitive to the application of the not only the shear stress non shear stress components like a tensile stress which we apply lot of vacancies will be because it will climb up or down lot of vacancies are generated that sort of a sensitiveness to non shear stress has not been observed for dislocations perfect dislocations in BCC material and another observation is also that compared to screw dislocations since the core is essentially confined to a slip plane it is easy for them to move and that move at very small shear stresses.

So, far we have considered the shorter translation vectors the observation in BCC is that 001 type of dislocation has also been observed when we deform BCC material, we have noticed that every slip plane especially 110 type of a plane contains 2 close packed directions, 2 dislocations are possible during deformation, some of these dislocations can interact for example, a typical reaction which is given where these 2 join together and generate 001 type if you calculate energy this will be 3 by 2 plus 3 by 2 correct no 3 by 3 by 4, 3 by 4 plus 3 by 4.

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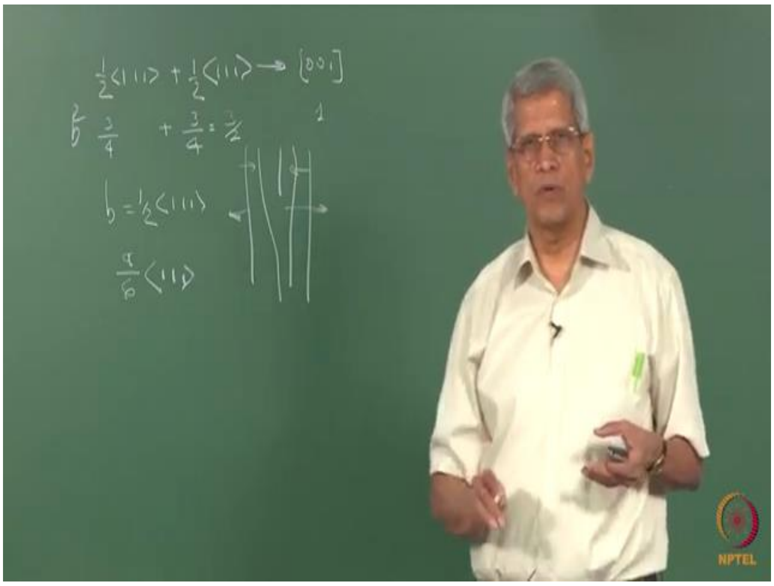

That is 2 types of dislocations this is essentially going to be one here it is 3 by 4 plus here also be 3 by 4 this is displayed value we calculate. So, this will turn out to be that is that is 3 by 2 correct. So, whereas, that is high, this reaction is also favorable, but as such the burgers vector of this dislocation is a quite high.

What has been observed is that when this dislocation has got a tensile configuration during that time generally if you look at when this location is cut a h configuration for h dislocation we look at it like this is this is of this is where the tensile stress is going to be there the compulsive stress is going to be there in this direction when the burgers vector is large it has been observed that under tensile loading this region act as nucleation for crack to develop that is below the extra half plane where the tensile stress are going to be there in many of the crystals which has been these the h dislocations with burgers vector 100 type which form that do not have no role in the plasticity, but they do act as crack nucleation sites.

So far we have considered perfect dislocations, 111 type, the screw and the h similarly 001 type dislocation also what it is effect we have considered that is and most of the FCC BCC system the experimental observation is that they do show twinning during deformation what is the mode in which that twinning can happen the stacking sequence along 112 direction is essentially a 6 layers stacking to understand this stacking sequence.

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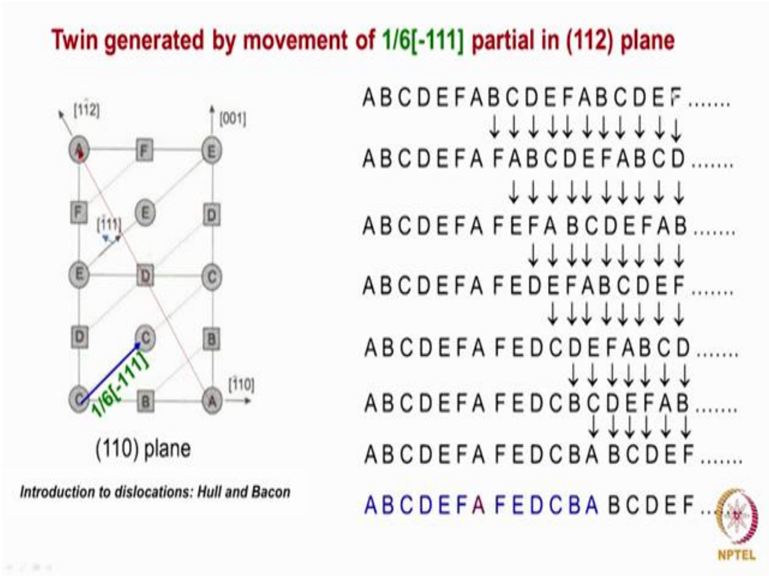

What I had shown is a close packed 110 plane in this plane this is the 001 direction, this is the 112 bar direction with respect to this specific plane this is the burgers vector, it showing the no this is actually wrong this is essentially 1 by 2 1 bar 1 2 that is 3 side essentially that B, what is being shown is half 111?

So, the stacking sequence is this is I think 2 layers of BCC one on top of the other has been placed and then what we are trying to look at it the projection of the atoms on 110 plane if this is the a plane the B plane 112 type of a plane this will be the one this is the CDEF because the that if you look at them a plane comes this is on the vector that a atom position matches this is how the different layers are stacked one on top of the other what we are showing it is a projection. In fact, if we look here this C position one a atom is also going to be there in this plane the C atom also overlaps with it similarly these shows the projections which are on the layer which is above all these circles which are being shown are atoms which are overlapping one on top of the other here what is being shown on the one which is above or below we can consider it what is essentially important is that.

If by a vector one third of this vector if I take it, essentially it will be from here to here if I move this atom will move from here to here. Similarly this atom will move from here to here that this atom moves from here to here this will be close to A position with respect in this direction it is close to F. So, the position of the layers will be shifting this shift of position is shown here in this stacking sequence here what I have done I am just showing here one particular layer the perfect stacking sequence is there ABCDEF along 112 direction this shows that this layer is being now shifted by a vector a by 6 111. So, when this shifting this B comes to C, C comes a like that they shift then the next layer after that has happened that is on every successive layer.

A displacement of A by 6 111 is being incorporated by giving a displacement of that vector now this A position will be shift at E position like this, if we consider everywhere here that this position get. Finally, what happens we have a stacking sequence which is there after 6 layers ABCDEF FCDCB because this is a mirror image of the other.

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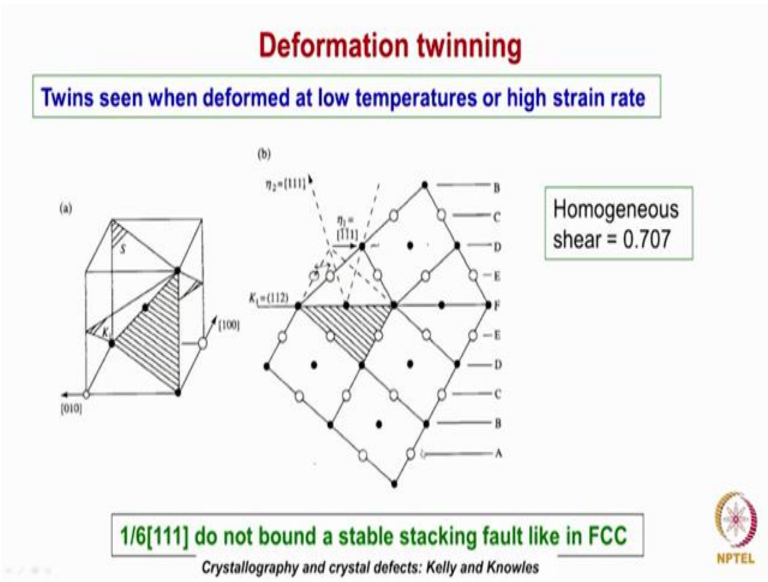

So, essentially we have formed a twin. So, or this same thing is being shown here where this side is untwinned lattice when a displacement vector of magnitude A by 6 111 moves on every plane then they shift the atoms to the positions you see that now here it has come to this position here it is identical to. So, mirror image is being created this way twins can be created this is the mechanism which has been put forward for twin mechanism in BCC if you remember in FCC the twins are essentially on 111 plane 112 direction here on 112 plane 111 direction is where the twining is taking place.

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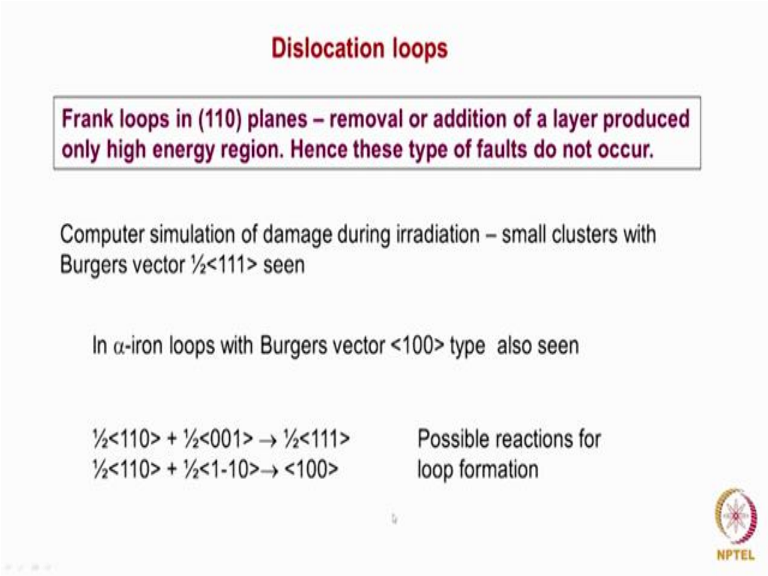

There it is 3 layer stacking sequence and here; it is a 6 layer stacking sequence. So, so far what we have considered the different types of perfect translation vectors in BCC their move movement in close packed planes whether fault will form or not then what is the mechanism by which a twining could occur in BCC lattice like in the case of prismatic loop which we have seen whether the prismatic loop can form in BCC lattice also or not that for we will consider because in FCC by condensation of vacancies or accumulation of interstitials in close packed plane frank dislocations or prismatic dislocations could be formed here also along this 110 plane. Suppose, we remove one particular plane small reason of it; it will generate away loop, but normally what has been seen in that this sort of loop if we create that is because a stacking sequence is ABABAB type of a stacking sequence if I remove 1 plane.

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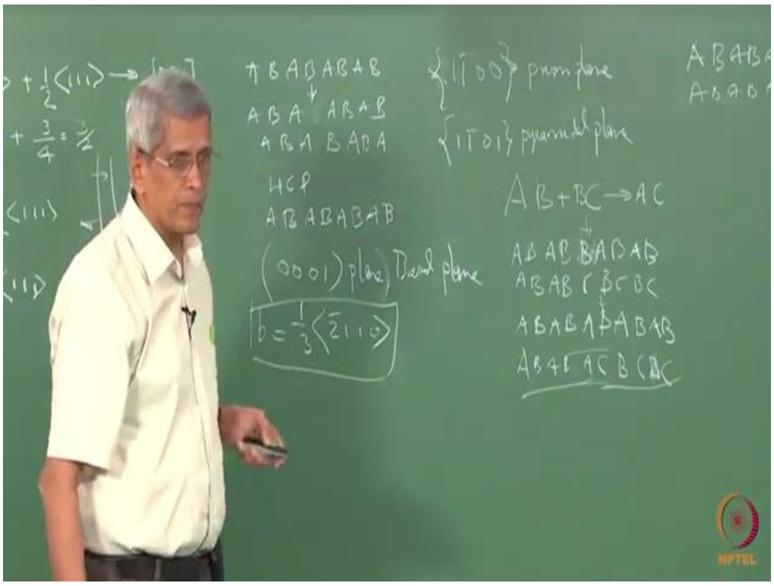

This plane is removed now the stacking sequence A position comes on top of an A position, but what is interesting here is that if by a movement of an another perfect translation vector if it reacts with it, it will move the B position to an A position to AB position. So, essentially a movement of perfect translation vector can restore the order.

So, this faults did not occur in the normal circumstances, but during radiation faults A, these sort of not faults during the radiation formation of a dislocation loops has been seen in BCC lattices many of the B are especially irradiation during radiation computer simulation of these loop sizes how they look like all these things have been looked at and it has been seen that is many small clusters are there with a half 111 burgers vector also especially in iron it has been seen that some loops have been seen with 100 type of a burgers vector also here the what all the different types of possible reactions by which these loops could form it is given.

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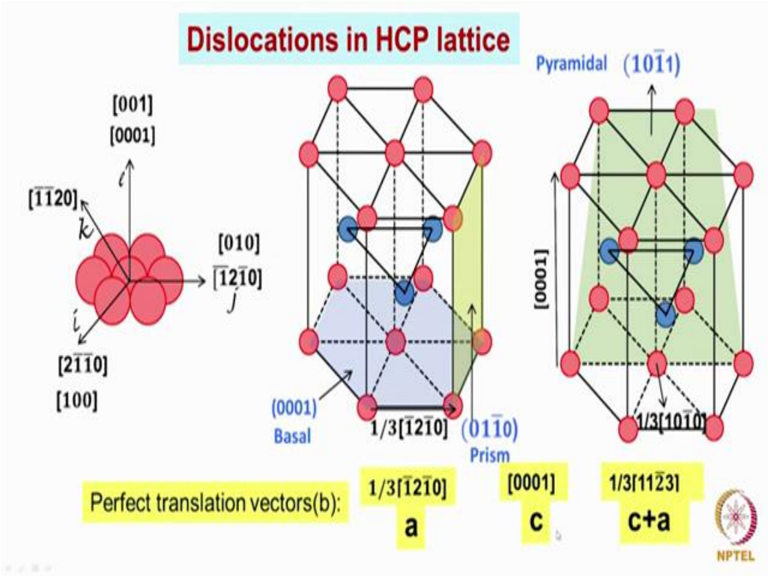

So with these we have looked at briefly what all the types of dislocations which can form in BCC lattice, we are not gone into looking at any specific system the interaction between the second wave it is a discussion of those aspects is beyond the scope of this work, but if one looks into a literature lot of data is available where people have published papers where they have looked at interaction between various types of dislocations in BCC lattice, but what we had shown here is that what all the types of dislocations which can form and which is the type of a dislocation which is mostly seen like during this discussion last one half an hour work one could make out that it is essentially.

1 0 that is screw dislocation perfect screw dislocation is the one which is mostly seen in BCC lattice let us look at because a HCP crystals are also important one because zirconium titanium these alloys they crystallize into a HCP form the temperature at which we wanted to use them they are in always in a hexagonal close packed state let us look at the crystal structure of a hexagonal close packed lattice in a hexagonal close packed lattice only 1 close packed plane is there that is called as the basal plane which is shown by light blue color here or violet color.

The atoms in the basal plane if we consider the hardware model they touch each other and in between 1 more layer comes which is displayed by A vector where A by 3 1 110 1 bar 0 type and then another layer comes the stacking sequence in this case in HCP in close packed plane is essentially or the basal planes stack means ABABAB type of a stacking sequence correct this is the way the stacking sequence goes what all the burgers vectors which the dislocations can have perfect dislocations.

One is that, this is one close packed direction this is another close packed direction this is the third close packed direction all of them are lying on 001 plane correct this is the basal plane close packed direction is 1 by 3 110 type. In fact, this dislocation the with perfect dislocation with this translation vector lies not only in this plane it is lying on 011 bar 0 type of this plane which is perpendicular to the basal plane and this can lie on a plane like this from here to here this is called as a pyramidal plane.

That is 1 1 bar 0 0 type of planes are called prism plane are called as pyramidal plane. So, these are all the planes in which this dislocation can lie.

So far we considered only one translation vector these translation vector turns out to be the smallest perfect translation vector in HCP lattice other translation vector is along the basal plane these planes are 001 planes are close packed they are stacked 1, on top of the other along ABAB type of a stacking sequence. So, a vector going from here to here is also a perfect translation vector and the nomenclature in especially people who work on zirconium or titanium alloys they use that terminology that 1 by 3 2 bar 110 type of a direction they call it as an A type of a dislocation because that is along the a lattice pyramidal correct a direction.

And this is along the 001 direction that where we considered as the C axis. So, they called this as the C and another is if I take a vector from here to here and from here to here; these vectorisation will give one from here to here; these vector that is also a perfect translation vector that vector is called as the C by a dislocation, it is essentially nothing, but A plus C adding to whether that vector gives another perfect translation vector.

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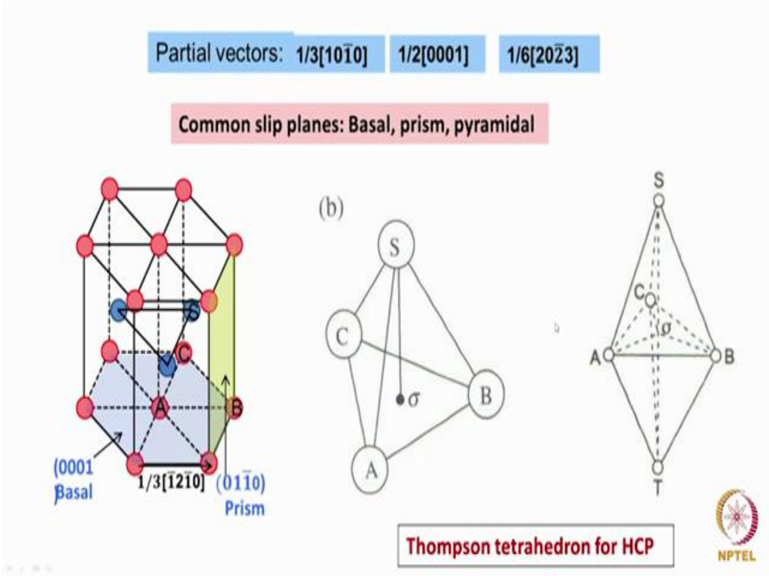

Out of which vectors, if we consider the dislocation which is perfect a translation vector that is the perfect dislocation with these burgers vector 1 by 3 2 bar 110, it can move on 3 slip planes correct all others they move on only one particular type of a slip plane that is one another is what all the types of partial vectors which we can have because here also it is a close packed plane to understand this better similar to what has been done in the case of an FCC material we can make a Thompson Tetrahedron and try to represent all the slip planes and the slip directions or as essentially the slip directions which is being done here; here if you look carefully I have marked this as A B and this is C and this is S.

And all these atoms; this is a tetrahedron like a Thompson tetrahedron only thing is that the plane containing ACB is the basal plane correct and if I consider the midpoint of it this; A sigma C sigma B sigma all of them will generate partials correct then if I take a distance from here to half the distance because 001 corresponds a perfect translation vector half of it will create essentially the partial vector correct then these are all the slip planes, but here the problem essentially is that in this way we have represented it a one perfect translation vector which is from going from here to here; we are not able to represent it further what is being done is a double tetrahedron that is one tetrahedron is there you join with an another tetrahedron which is going to be there at the bottom we just show that.

Once that has been taken not only these vectors on the basal plane that is ABBC and a c are the perfect translation vectors in a basal plane these ST represents the perfect translation vector perpendicular to a basal plane then this vector SA plus this vector TB if we take it that will represent a vector from A to this point, these are all considered as the 3 of the shortest translation vectors in HCP lattice.

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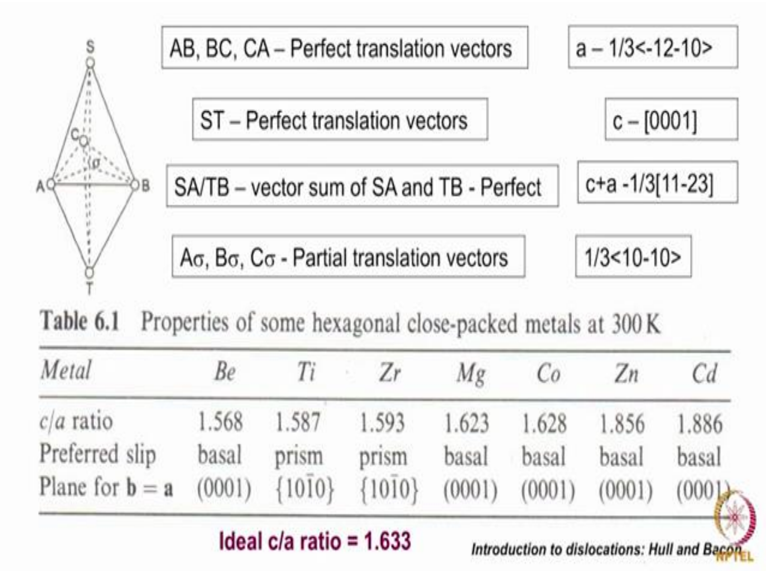

Table 6.1 Properties of some hexagonal close-packed metals at 300 K

Metal	*Be*	*Ti*	*Zr*	*Mg*	*Co*	*Zn*	*Cd*
c/a ratio	1.568	1.587	1.593	1.623	1.628	1.856	1.886
Preferred slip	basal	prism	prism	basal	basal	basal	basal
Plane for **b** = **a**	(0001)	$\{10\bar{1}0\}$	$\{10\bar{1}0\}$	(0001)	(0001)	(0001)	(0001)

If you look at the tetrahedron that ABBC and a c are the perfect translation vectors and that is generally designated as A and this is the magnitude I have this is the burgers vector and from this we can find out the magnitude.

ST is another perfect translation vectors called as the C and the vector is 0 001 this is this is the convention which is used to represent these vector SA plus TB because these 2 are at a 2 different points. So, SA stroke TB it is written that is nothing, but of a vector sum of SA and TB that generates C plus a c plus a dislocation and these vectors a sigma B sigma, they generate partial translation vectors if in these table shows with expect to C by a ratio, what we have which are the plane in which slip can occur commonly in different hexagonal materials if you have got hexagonal crystal structure if it consider a hardsware model like this putting a atoms on top of it and try to construct it that hexagonal close packing if we take then the C by a ratio in an ideal case is 1.633.

If we look at titanium and zirconium a c by a ratio is less than 1.633 magnesium cobalt zinc cadmium if you look at that magnesium and cobalt has got values close to 6.33

beryllium has a very less value zinc and cadmium has got a value which is high generally what has been seen the one which has got a c by a ratio less than 1.633. There the slip has been found to occur on 101 bar 0 type of a plane though the closes packed plane is the basal plane which is 001 where as in cases where the C by a ratio is close to 0.63 or higher on basal plane is where the slip has been found to occur and beryllium is an exception where even with a low value of a c by a ratio which is smaller than an ideal case still in basal plane deformation occurs.

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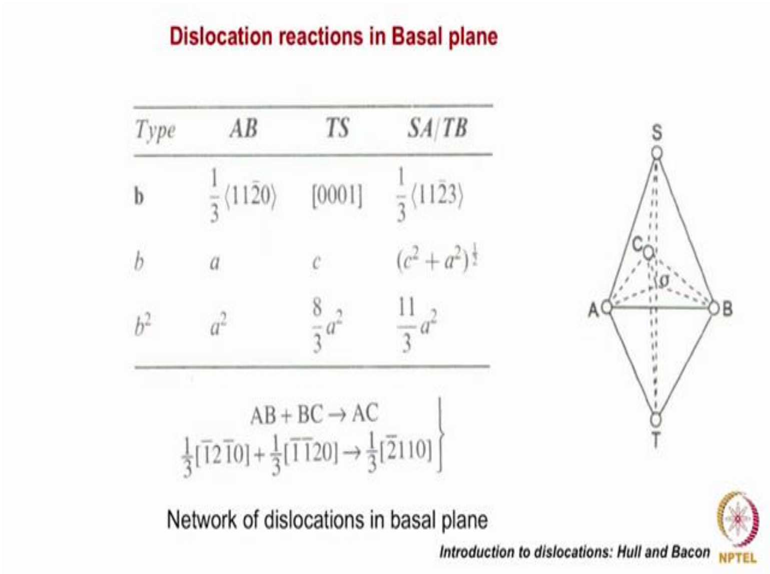

In this transparency what I had shown is the different vectors burgers vectors of perfect dislocations what is going to be the magnitude of this vectors and the b square value to find out the energy that is self energy of a dislocation one interesting thing which we can consider it is that if 2 perfect dislocations like we have seen that in the same slip plane the dislocation AB plus BC can give rise to CA the same type of a reaction which it can happen AB BC CA or a c all of them are perfect translation vectors in close packed plane if a dislocation.

With a burgers vector is AB interacts with another B C, it should give raise to 1 be the vector a c, the a c is also a perfect dislocation with a perfect translation vector. So, essentially what is going to happen is that this sort of a reaction as often been seen in many HCP materials and these dislocations join together to form a network some external network of dislocations had been which one can see in many HCP material.

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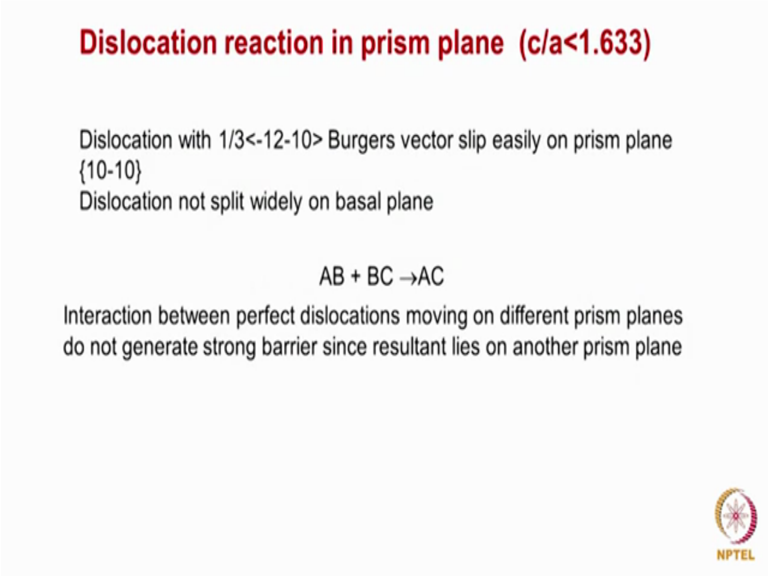

Suppose we assume that these dislocations because we have seen that each of these dislocations with these translation vectors perfect translation vectors that is 1 by 3 1 2 bar 110 type of a burgers vector. They can lie on prism plane each one of them can lie on different type of a prism plane that is what it will happen if that is what the case and the dislocations are moving in those planes they can come and interact what is the sort of interaction which can occur there what happens is that if a and the another thing also which we should notice is that for each of these directions if we consider that is the dislocation with these burgers vector the prism plane is specific on in that plane.

So, in another plane another specific dislocation is there a type of a dislocation these dislocations when they interact they will be generating an another dislocation of the type ac, but this a c dislocation turns out to be like we did it in the case of an FCC material dislocations are lying on different slip planes when they come to a and this interaction if you look at this reaction this is an attractive reaction. So, it is possible and they generate anther dislocation which is an a type, but it tries on another prism plane if it lies on another place you can easily move where as in the case of FCC material it is lying on a not on a close packed plane because of that the dislocation becomes aside right here that does not occur these reactions generally generate the dislocation which is essentially a different dislocation.

Then now let us look at what all the type of stacking fault which it can form the other type of dislocations also other than dislocation with these a type of dislocation C plus A dislocation has got a large burgers vector it has clearly been seen under heavy deformation and all, but otherwise most of the time these type of dislocations which are observed what all the types of faults which it can form because this is also a close packed plane and in this close packed plane every atom there is the next layer when we place an atom on the next layer it can be placed on 2 positions on A plane B and C positions are there where an atom can be, but essentially the stacking sequence is ABAB type of a stacking sequence, correct.

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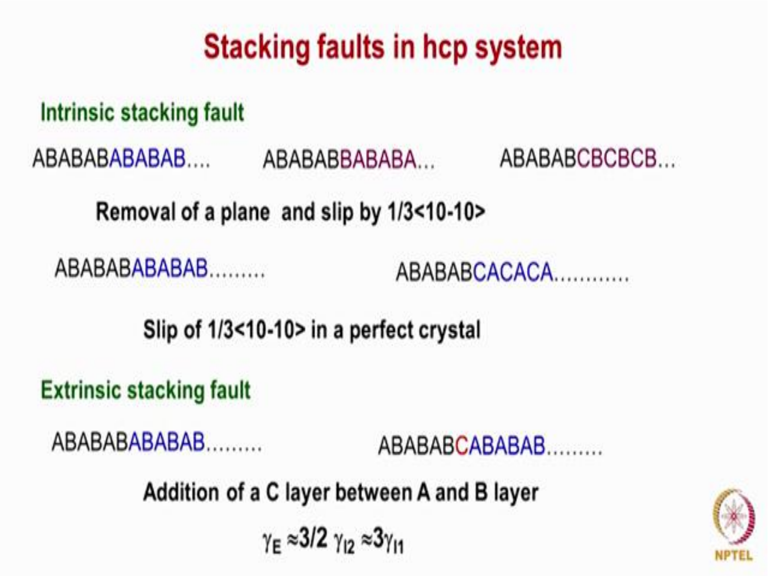

In these type of a stacking sequence, suppose I remove 1 layer if I remove 1 A layer then what it will; it become the stacking becomes ABABAA no ABABBAB, this is a type of a stacking sequence, which it happens, correct, in this particular type of a stacking sequence if it interacts with an another one, this will be a high energy fault if it interacts with an another partial which moves this to C position AB, this will become C, this will become B that is ABAB stacking sequence are changes to a different stacking sequence and the other side also it is an ABAB stacking sequence, but with the fault which is coming in between because of that the same stacking sequence is not being followed this is by removal of a plane and a slip by 1 by 3 1 0 1 bar 0 type of a vector which is a partial translation vector what is the other way in which it can happen if a vector by 1 by

3 1 0 1 bar 0 type of a partial which moves on a some particular plane what it will do when the stacking sequence is AB.

AB becomes direct suppose we assume that here it moves this B layer, we will move to a c layer position, correct, AB layer moves to C position then what will happen to the a layer will go to the B position B layer will go to the C this will go to the A, this will go to B this will go to c; that means, that the stacking sequence from ABAB, it changes to CBCB, but the movement of a partial in the case of an FCC lattice a fault is created, but if you look at the stacking sequence on either side of it remains ABCABC, but only thing which we should notice here is that a 3 layer stacking has been introduced here which is similar to that of a BCC which is similar to that of an FCC.

So, essentially a unit cell of FCC is created in hexagonal close packed itself by generation of a stacking fault these are all essentially extrinsic stacking fault extrinsic stacking fault can be generated if we add a layer.

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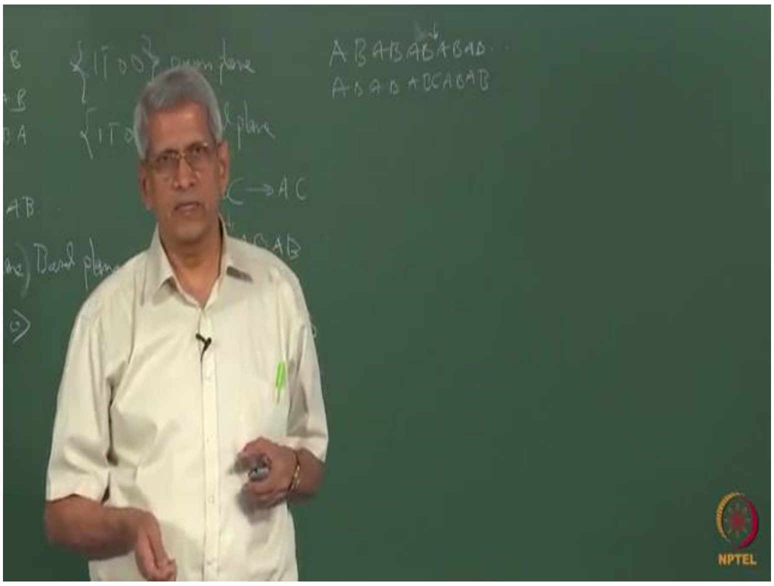

That is in this stacking sequence assume that we had a layer either here or we assume that we had a layer here between B and A, we are adding a layer in the C position. So, this we can here either side of it if we look at it, it looks like a ABAB and the other side also ABAB, but an ABC stacking has come in the middle this is an extrinsic these are all the 3 possibilities people have done a lot of calculations to find out in many of these crystal systems what is the energy of these faults it has been seen that the stacking fault energy of the extrinsic stacking fault is the highest that of this fault which is shown in the middle this one it is going to be intermediate and this has got the lowest fault energy that is the observation, but generally these fault energies are very high normally faults has not been observed in either in zirconium or titanium alloys, but these are the fault in principle can form, correct.

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Most of the this one here also under alloying addition in some of the materials had been seen, but normally otherwise in pure zirconium or this one if you consider it generally these sort of faults not seem.

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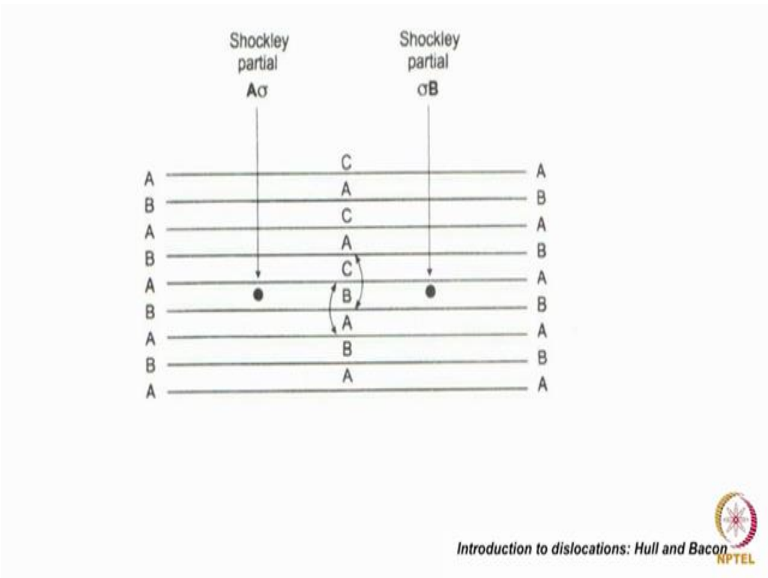

This is essentially show in the structure of the faults with A B C stacking sequence when a perfect dislocations that is if a perfect dislocations splits in to a partial. Then, that partial if they separate they should be able to generate a stacking fault and normally this has not been observed in many of this material.

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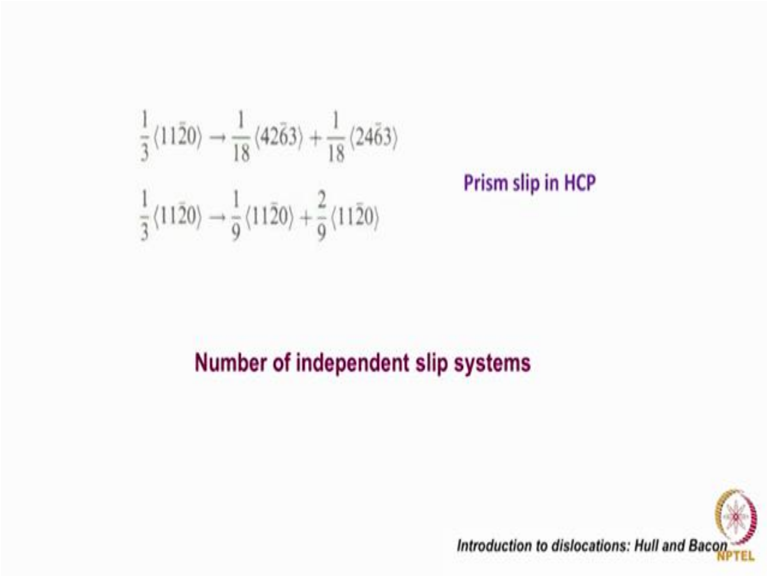

Generally, on prism planes there is suppose a deformation like a zirconium and titanium essentially the prism plane is where the slip is occurring the a type of a dislocation that is a type of a dislocation has got a burgers vector of this type then these dislocations they can split into 2 types of reactions which has been thought of that they can splits into partial and they can generate stacking faults. But the observation is that this sort of deformation has not been observed at all that is the truth it may have both these systems zirconium and titanium.

In fact, in all these systems essentially if one looks at it the number of independent slip systems which are available for slip in HCP material or 2 in a prism plane and 2 in a sum totally only 4 the number of slip system criterions is that we should have a 5 independent slip systems are required to compensate for that some of the with the burgers vectors which have got higher magnitude is that they are generated or in many systems twins do form twinning has been observed in many hexagonal close packed materials.

The twinning I will not talk about it here may be when we talk about twinning as a separate topic then we will consider this. So, far what we have done we have looked at the different type of a dislocations which it can form perfect as well as the partial though we have considered the various reactions by which partials could form in general is the perfect dislocations which are responsible for slip in HCP systems correct and in HCP systems also since is a close packed twins which we are stacking removal of a condensation of a vacancy in one plane or accumulation of a interstitials in a plane close packed plane like find dislocations we can form some dislocations here as well.

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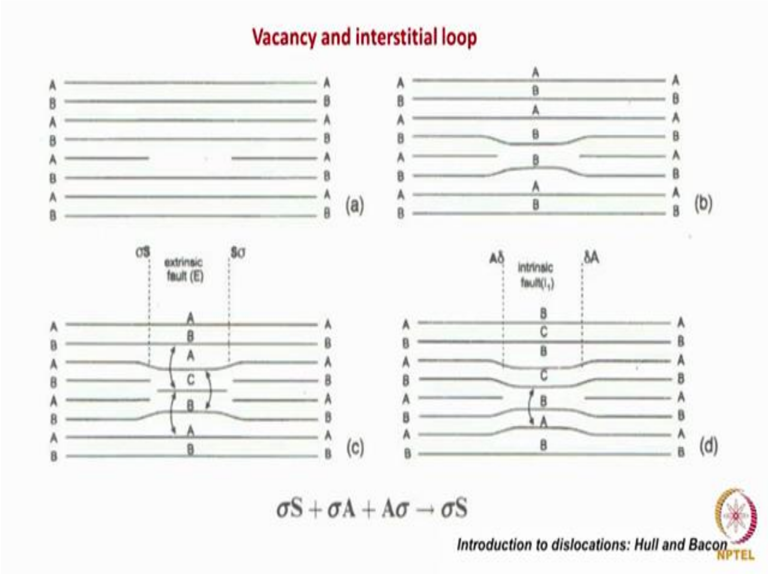

We can see loop or interstitial loop that sort of a reaction, but here the things are seen to be much more different from that of what has been seen in hexagonal close packed system because here what happens if a condensation of a vacancy takes place like in this case then you find that too may be atoms are coming close together this essentially generates a high energy fault in the case of FCC when a condensation takes place they can generate a low energy stacking fault that just does not work our here now in this particular case the movement of an another partial of the type sigma B this could be converted in to.

This B layer could be move to the C layer. So, that an intrinsic stacking fault could be generated that is what it is expected to happen.

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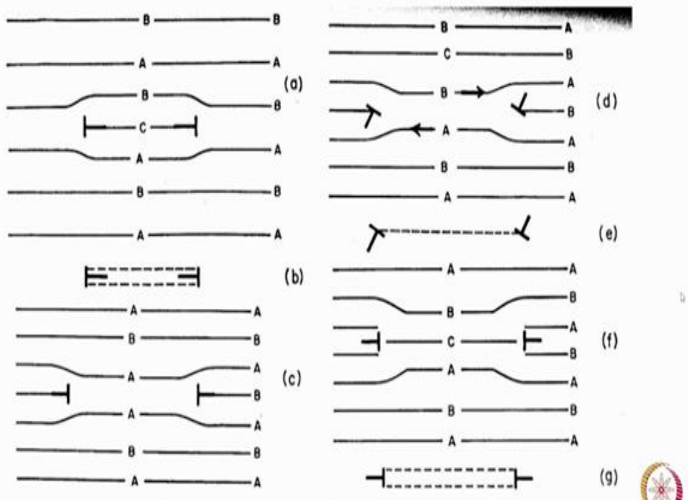

FIGURE 4-19. (a), (b), (f) and (g) Frank dislocations in an h.c.p. lattice; (d) and (e) composite dislocations.

Actually the same thing which I had explained I had shown here because when this one dislocation moves and changes it then you can see that the nature of vector the extra plane which is going to be it is not in the slip plane these are all the types of reactions which it can occur. So, essentially what we have considered is that from the crystal structure what all the types of a translation vectors which can occurred in BCC and HCP lattice and in principle. They can split and generate especially in the partials and generates stacking fault, but the experimental observations as well as some of the theoretical calculations and computer simulations show that that does not occur.

Now I will stop here if one who wants more detail about the various types of a dislocation and dislocation interaction one can go through other books in detail, but that is beyond the scope of these lectures in the next class we will look at essentially multiplication of dislocations and interaction of dislocations we will look at it in some detail. We will stop here now.